ASSESSMENT ON MACHINABILITY OF NiCoCr BASE SUPERALLOY

A SYNOPSIS

Submitted by

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1. INTRODUCTION

It is a functional material of present research work. Nickel-based superalloys have gained more importance, nowadays, owing to extensive applications in aerospace, marine, nuclear reactor, and chemical industries [1]. Various properties, such as superior mechanical and chemical properties at elevated temperature, toughness, and exceptional resistance to corrosion and thermal shocks, are mainly accountable for their widespread application. However, machinability of nickel-based superalloys is a critical aspect that influences functional performance including fatigue life of the component [2].

Initially, their development was encouraged and driven by the insight that the efficiency of thermal power generation machines can be increased by increasing the combustion temperature and/or pressure. Consequently, they have been widely used in high-performance combustion engines, such as gas turbines in aircraft, and for power generation in thermal, nuclear and fossil fuel power plants. The typical nickel-based components in this energy sector are rotors, turbine discs, blades, shafts, bearings, spindles and bolts, as well as casings for stationary gas and steam turbines. In the aircraft industry, most of the rotating turbine parts and also the casings, links and some of the engine mounts are typically made of high-performance nickel-based superalloys [3]. They are developed through directional solidification and on post processing chance has raised to increase the γ' in the material [4].

Development in nickel – based superalloy is still found vacuum for the past two decades. In a very specific, the progress on nickel alloys is continuous challenging for turbine engines, heavy machineries and in high temperature applications. The origin of the problems in the development of nickel – based superalloy is to achieve good mechanical properties and excellent metallurgical qualities. It is a single crystal nickel – based superalloy, developed through a directional solidified process [5]. They are highly recommended for high temperature applications and as wear resistance materials [6].

Wire Electro Spark Erosion (WESE):

Wire Electro Spark Erosion (WESE), also known as Wire-Cut EDM or Wire Erosion, is a specialized machining process that utilizes electrical discharges to precisely cut conductive materials into complex shapes. Wire EDM is particularly well-suited for producing parts with tight tolerances, intricate geometries, and delicate features.

Laser Beam Machining:

Laser machining utilizes a high-intensity laser beam to heat, melt, or vaporize material from a workpiece. It is highly precise and can be used for cutting, welding, engraving, and surface treatment of various materials, including metals, plastics, and ceramics. Laser machining offers fast processing speeds and can achieve intricate details with minimal material distortion [7].

Micro- Drilling Process:

Micro drilling is a specialized machining process used to create extremely small-diameter holes in workpieces with high precision. This process is particularly important in industries such as microelectronics, medical devices, aerospace, and automotive, where miniature components and parts are common. The process of Micro EDM requires specialized equipment capable of providing precise control over electrical parameters, such as pulse duration, pulse frequency, voltage, and current [8].

Process Optimization:

Process optimization refers to the practice of improving efficiency, reducing costs, increasing productivity, and enhancing quality within a process operation [9]. It involves analyzing existing processes, identifying areas for improvement, and implementing changes to make the process more effective and efficient. Evolutionary algorithms (EAs) are a class of computational methods inspired by the process of natural evolution. They are used to solve optimization and search problems by mimicking the principles of natural selection, genetic inheritance, and survival of the fittest [10].

Adam Gene Algorithm:

Genetic Algorithm is one of the versatile techniques following natural process and simulating the human genetics systems. The Adam-Gene algorithm is created by changing a functional parameter. The concept is derived from Adam and Eve, having variation in population size [11]. The algorithm starts with initial population of two individual pair of chromosomes/population, simulating the Adam and Eve. The crossover and mutation are different from the conventional algorithm. Further, mutations can be carried out or it can be restricted for newly generated offspring (new couples). New

operator introduced for Adam – Gene Algorithm is Death. In which the parent chromosomes can be alive and live with their offspring. This will lead the population size larger with respect to iteration and becomes increasing called Genetic Algorithm with varying population size [12].

2. LITERATURE REVIEW

Dawood and Salim [13] has been developed a computer model such that the strength of nickel-based superalloys can be calculated as a function of alloy composition, heat treatment and temperature in aircraft engines and land-based gas turbines where high strength at elevated temperatures is required. It has always been an important task to develop alloys with better high temperature properties. Satish et al [14] Improved properties may be achieved by modifying alloy chemistry and processing route. Nickel-based superalloys are likewise called as hard to-cut or advanced materials due to their high working temperatures, solidarity to weight proportion, high hardness, durability, creep opposition and low, warm conductivity.

Manjaiah et al [15]. tried to investigate the impact of the chosen process parameters namely, spark on time, spark off time and voltage. The ternary element copper and the percentage variation of copper in Ni based superalloy was shown a notable variation in the surface finish and cutting rate. It was also noted, the voltage primarily influences the percentage of elements in the recast layer. The addition of 20% copper in the Ni based superalloy improved the cutting rate. The microhardness was more on the outer surface due to the formation of recast layer. The maximum thickness of recast layer was measured as 60 μm, the maximum microhardness of 900Hv was measured in the outer layer, the micro hardness keeps on decreasing as the depth increases. Negligible changes on the microhardness were seen after the 60 μm depth. The same trend was noted form most of the work in WEDM

Moradi et al [16]. showed that using the desire function technique, increased surface hardness with considerable penetration and least ferrite percentage may be achieved by increasing laser power and lowering other parameters. The confirmation of the improved outcomes was done utilizing experimental tests. The maximum hardness,

maximum depth of hardness, and minimum ferrite percentage were all attained in this study under ideal conditions, achieving 670 Vickers, 2.2 mm, and 0.45%, respectively.

Jeyaprakash and Yang [17]. studied the laser-processed Nickel based superalloy was examined to reveal its structure, phase analysis, microhardness and wear resistance. He reported that in Nickel based superalloy, M23C6 carbides were noticed as rich in chromium and spread over the grain boundaries as fine particles. During laser surface melting, the MC carbides are slowly decomposing and produce carbon. The laser beam melting regions were showing with subtle variations in the distribution and shape of γ' precipitates. The material loss on base material was ~ 6.70 g which is higher than ~ 1.12 g (LSM) for the fixed sliding distance. This was due to improved hardness of substrate after laser processing. In melting period, the formation of γ' precipitates on the cellular boundaries are steady with rapid diffusion of solute in these regions and showed a strong network to enhance the wear resistance of melting layer.

Hasan et al [18]. reviewed the lasts micro drilling methods and techniques, categorizes them into different groups, highlights recent developments and new trends, and depicts the future requirements in the field of micro drilling. Both conventional and non-conventional micro drilling techniques used in modern age applications are categorized. He said that, conventional micro drilling makes use of drill bits of different configurations such as twist, spade, D-shaped, single flute, compound drill and coated micro drill, while non-conventional micro drilling involves electrical, chemical, mechanical and thermal means which include laser, EDM, ECM, SACE, electron beam, ultrasonic vibration or combinations of these approaches.

Nalbant et al [19]. obtained the following conclusions from the research experiments on the influence of cutting parameters, tool material, and shape on the tool performance when cutting nickel-based superalloys: when the cutting speed is increased, the cutting force decreases, and when the feed is increased, the cutting force decreases and the cutting temperature rises. The comprehensive experimental results showed that the cutting speed was 250 m/min, and the cutting force at that time was the minimum. In the high-speed turning of Inconel 718 with a K20 carbide tool.

3. RESEARCH GAP

The following research gaps were identified from the review of literatures

1. Some investigations were carried out for the ternary Ni based alloy, though some researchers performed machining studies on ternary Ni based superalloy such as NiFeCr, NiCoFe, NiTiCo. But the availability of literatures in the Nickel-cobalt-chromium (NiCoCr) alloy were proportionately low.

2. The machining characteristics of NiCoCr base superalloy is limited, especially with the mechanical based micro machining process.

3. The deposition of the carbon over the exterior surface of the NiCoCr base superalloy during the WESE process was found limited needs further analysis. The effect of the process parameters towards the machinability of the NiCoCr base superalloy needs further clarification.

4. The conventional way of micro drilling in the NiCoCr base superalloy was not found much in the literatures. The effect of notable parameters on the outer diameter of the drilled hole needs further investigations.

5. The thermal effect and the helical rotation during trepan drilling using laser beam machining was limited for the NiCoCr base superalloy.

4. OBJECTIVES

The main objective of the present work is to analyze the quality characteristics of super alloys, namely NiCoCr base superalloy.

I. The characterization of the NiCoCr base superalloy through optical microscopic.

II. The Machining of NiCoCr base superalloy using the (a)Wire Electro Spark Erosion process, (b) Laser beam drilling process (c) Mechanical based micro drilling using tungsten coated carbide tool.

III. Surface Characterization of machined NiCoCr base superalloy samples using SEM (Scanning Electron Microscope) and OM (Optical microscope).

IV. Optimizing the machining parameters to achieve the minimum surface roughness, maximum Material Removal Rate and Profile dimension for machining NiCoCr.

V. To identify the individual contribution of machining parameters involved in the WESE and Laser Beam process using ANOVA

5. EXPERIMENTAL METHODOLOGY

Based on the research objective the following experimentation and characterization were performed. The complete workflow of research with details of experimentation and characterization performed is depicted in Figure 1.

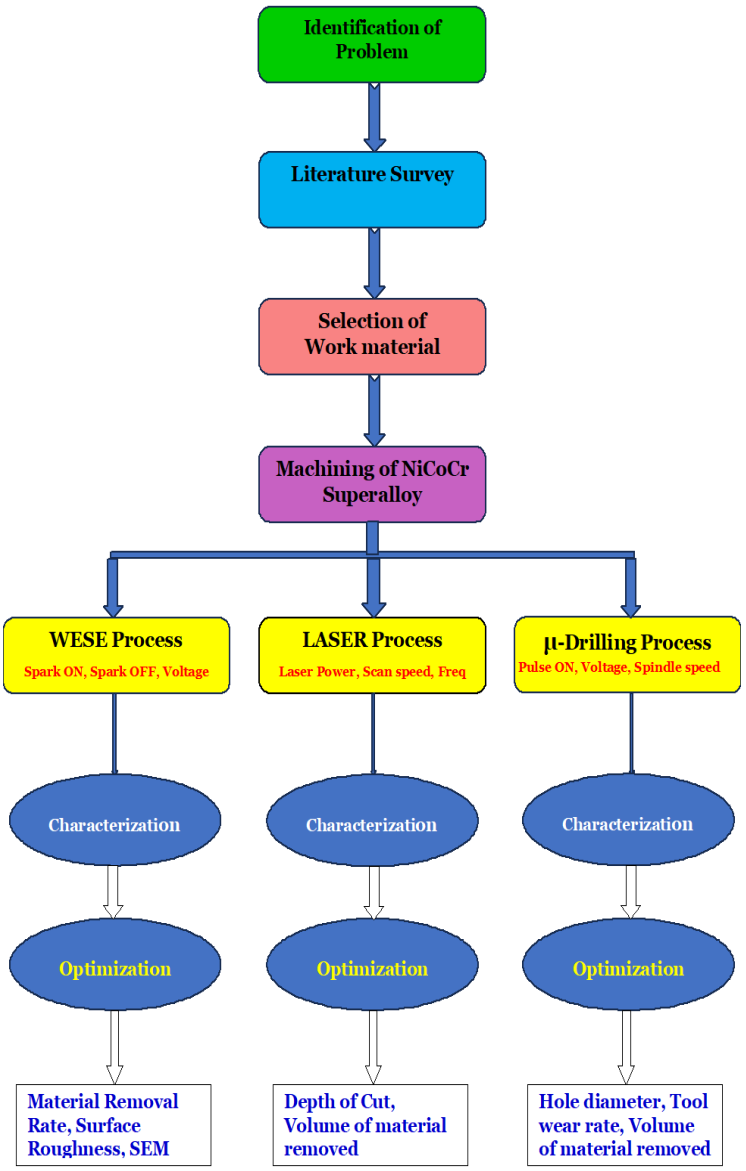

Figure 1 Experimental Methodology adapted for current research

6. MATERIAL AND ITS CHARACTERIZATION

In the current research, a commercially available NiCoCr superalloy was chosen for the study. The NiCoCr superalloy was procured from Ultimate Enterprise, Tamil Nadu, India.The shape of the procured NiCoCr superalloy is a circular rod of diameter 10 mm. The NiCoCr alloy was cleaned with acetone to eradicate any undesirable elements over the surface. The elemental analysis was done by Omega inspection and analytical laboratory, Guindy, Chennai. The Foundry Master Pro - Optical Emission Spectrometer (OES) (Make: Oxford Instruments, Germany) was used to study and record the elemental weight percentage of NiCoCr superalloy and the same tabulated in Table 1. The properties of the NiCoCr superalloy are as follows; density – 8.62 g/cc, Hardness – 379 HV yield strength – 828 Mpa and ultimatetensile strength – 966 Mpa with a micro hardness 341 HV.

Table 1 Elemental weight percentage of NiCoCr base superalloy

NiCoCr	***C***	***Cr***	***Co***	***W***	***Mo***	***Ta***	***Al***	***Ti***	***Hf***	***Ni***
Element wt. %	0.07	8.2	9.1	9.3	0.6	3.0	5.5	0.7	1.3	Balance

7. EXPERIMENTATION

7.1 Wire Electro Spark Erosion (WESE) technique

The material composition of NiCoCr base super alloy used for the experimental investigation is given in Table 1. The material is in the form rod with a diameter of ϕ10mm used to machine with wire electro spark machining (WESM) process. The machining process is performed on Electronica wire cut discharge machine using 0.3 mm copper wire with dielectric fluid. Machining studies are performed with different process parameters, such as spark duration and applied voltage as given in Table 2.

In addition, the potential (230v) and current (12A) are maintained same throughout the processes. The cutting wire travels is in the range of 3m/min with a cutting speed of 1mm/min, tension of the wire is 7kg/mm is constant for entire process. The other process conditions such as Potential input (230 V), Peak current (12 A), dielectric medium (Deionized water), wire feed rate (3 m/min), wire material (half hard copper wire), wire tension (7 kg /mm), cutting speed (1 mm/min) and duty factor is maintained constant as 90% throughout the experimentations.

The outcome of WESE machining process were surface roughness (Ra) and Material removal rate (MRR). The SR of the machined specimens have been measured using Surftest SJ410 surface roughness tester (Make: Mitutoyo South Asia Pvt. Ltd) instruments.

The MRR of each specimen has been calculated using the formula given in equation 1.

$$MRR = \frac{Sectioned\ area\ during\ machining\ x\ width\ of\ cut}{Machining\ time} \qquad \text{.....(1)}$$

7.2 Laser beam micro cutting

The micro profile of dimension of 1000 µm x 250 µm using Nd – YAG laser (Make: Lee–Laser; Model: 905 SLFS; from Direct Light Incorporation) femtosecond machine. The input process parameters such as laser power (2, 3 and 4 watts), scan speed (50, 75 and 100 mm/sec) and pulse frequency (5, 7 and 9 kHz) are varied at different combinations to perform the micro engraving on NiCoCr base superalloy. During micro engraving the heat energy developed from the laser pulse will melt the material and induces local vaporization. The work chamber is controlled with argon gas (shielding) at a pressure of 3 – Bar to protect the machined surface from scale formation. The dimensional accuracy of the micro profile is measured the scanning electron microscope (Make: Ziess, Germany). Completion of top profile (length and breadth) measurement the samples are sliced with advanced process to measure the cross-sectional dimensions. Sliced samples are mounted; metallurgically polished and depth of the groove are measured using Optical microscope (Make: Vertimet, India). Further the influence of input process parameters is studied using a statistical tool.

7.3 Conventional Micro drilling

The experiments were performed at the multi-purpose MIKRO tools micro machining Centre. Th e level of parameters was selected on the basis of literature survey. The parameters such as tool rotational speed, work feed, and cutting depth. Drilling of micro holes was performed on NiCoCr base superalloy work material with the help of 0.3 mm Titanium nitride coated tungsten carbide tool. This is based on the design of experiments to obtain an output response like the diameter of micro holes and the surface roughness were measured using the scanning electron microscope. The performance parameter value of MRR and Machining times were evaluated by theoretical formula as mentioned in equation 2.

$$Machining\ time\ [tm] = \frac{Length\ of\ drill\ hole}{Spindle\ speed\ x\ feedrate} \qquad \text{.....(2)}$$

8. RESULTS AND DISCUSSION

8.1 Effect of SON, SOFF and V on the Material removal Rate (MRR) using WESE method.

Removal of material depends upon the intensity of electro spark produced during machining. The material removal tends to follow increasing trend with maximum pulse on time and applied voltage. It directly relates with the increase in voltage and prolong pulse duration. The efficiency of electro spark has supported to remove maximum material. For minimum pulse on, the time span of electro spark intensity is short to remove the material less in volume. It has been understood that, the material removal has gradually increased to a maximum of 1.169 mm3/min with maximum pulse on time 120 µs at 30v. In this research, the material removal was found to be maximized in a steady state with increase in pulse on time.

This indicates that, the efficiency of the plasma spark has highly supported towards material removal in large-scale. However, this will be interrupted against the pulse off time as designed for machining experimentation. The increase in pulse of time will pull the material fusion and evaporation during machining process; subsequently the material removal has found fluctuating and has reduced to some extent. As a result, the

distraction in material removal over the machined surface may lead to some defects in terms of metallurgical aspects. It also directly influences on surface roughness with craters and valleys, due to thermo metallurgical actions.

8.2 Effect of SON, SOFF and V on the Surface Roughness (SR) using WESE method

The surface roughness of the electro sparked machined samples were measured with respect to applied voltage and pulse duration. The pulse off time on electro spark machining has high impact over the surface roughness. For minimum pulse off time (at 50 μs), the surface roughness is less and it is in the range of 2.2 to 2.45 μm.

During the same machining process, with increase in pulse off time, the distraction or shortened pulse duration has highly influenced the machined surface to cause rough layers. Similarly, the surface roughness has found to be less for average voltage (20 volts) within the range of 2.2 to 2.4 μm. Wide variation in surface roughness has been recorded for different pulse on time. The significant reason for changes in surface roughness is due to pulse duration and wire feed rate.

8.3 Optimization of machining parameters on WESE method

Evolutionary search algorithm is one of the ancient algorithms used to predict the optimized process for the constraints and / or unconstrained condition. These algorithms are the bio mimics of evolutions in the biological systems. Literatures are available to report on genetic algorithm (GA), particle swarm optimization (PSO), ant colony optimization (ACO) and still the developments on bio – mimics are unrelenting. As an evolution in the bio – mimic algorithms, the chromosomes / populations are handled in different form to increase the efficiency of the algorithm. One of the concepts in handling the chromosomes / population is variation in size (number of chromosomes / populations) defined in the multi population in genetic algorithm. The development of the population variation in genetic algorithm has reached to expand as Adam – Eve Gene Algorithm. The factors in adam – gene algorithm is slightly modified from conventional genetic algorithm. Some of the highlights are as crossover (reproduction) from single pair randomly generated chromosomes, mutation in chromosomes and death of chromosomes after a defined number of generations. In this algorithm, the chromosomes generated or

born during crossover are limited to sustain (to live) for three generations only. The Adam – gene algorithm is similar to Genetic Algorithm with varying population size (GA Vs PS), with a control in population through the death factor. It will control the population by removal of chromosomes after three consecutive generations. The regression equation for the profile length (Eq. 3) and breadth (Eq. 4) derived from the statistical tool with the experimental data are as follows:

$$f(x) = 0.5Ra + 0.5MRR \quad \text{..... (3)}$$

$$P_{best} = \frac{1}{f(x)} \quad \text{..... (4)}$$

In this case, equal weightage is given for each response, as both surface roughness and material removal rate are important to identify the quality of the machining process. The best parent chromosomes (P_{best}) will be identified during each generation and the search evaluation goes up to fifteen generations. At each generation, the population increases in terms of square. At the same the chromosomes at each generation are mutated and produces a pair of child chromosomes. Research papers are available to discuss about the algorithm in details. In this research, the multi objective optimization process is performed to identify the best process parameter to machine Nickel-based superalloy using a wire electro spark material removal process. The process optimization is performed to find a globally best process parameter to achieve minimum surface roughness with minimal material removal. Objective functions are derived from the Taylors Equation (Eq 3 and Eq 4) for surface roughness (Ra) and material removal rate (MRR) respectively. Based on the Analysis of variance the chosen parameters are calculated.

8.4 Micro profile using pulsed laser

The micro profile on NiCoCr using Laser beam was discussed in this section. The dimension of micro profile is 1000 µm x 250 µm were machined. The input process parameters such as laser power (2, 3 and 4 watts), scan speed (50, 75 and 100 mm/sec) and pulse frequency (5, 7 and 9 kHz) are varied at different combinations to perform the micro engraving on NiCoCr base superalloy. The uniformity of the engraved profile is varying due to the change in input process parameters. Variation in the top layer has a

high impact over the blind end of the profile. It is based on the intensity of the layer energy developed during the engraving process. Further the engraved structures sliced to read the depth of micro structure.

The depth of the micro profile is measured using the optical microscope. The statistical result infers that the depth of the micro profile has wide range of variation from 476 to 650 µm for the slow scan speed (50 mm/sec) and found to be converged for the maximum scan rate of 100 mm/sec. From the result, the 2 watts, 100 mm/sec and 7 kHz process condition the laser engraved profile with cross section of the groove are observed through the SEM and optical microscope as shown in Figure 2. The profile of the laser engrave is uniform and the depth of profile is getting narrow compared to the previous condition. In this case the carbon distraction is comparatively less as the laser scan speed is higher.As the depth of material removed is undefined and the dimensional stability depends on the scan speed. For slow scan speed the material ablation at the blind end is narrow and deep and this can be avoided with average scan speed.

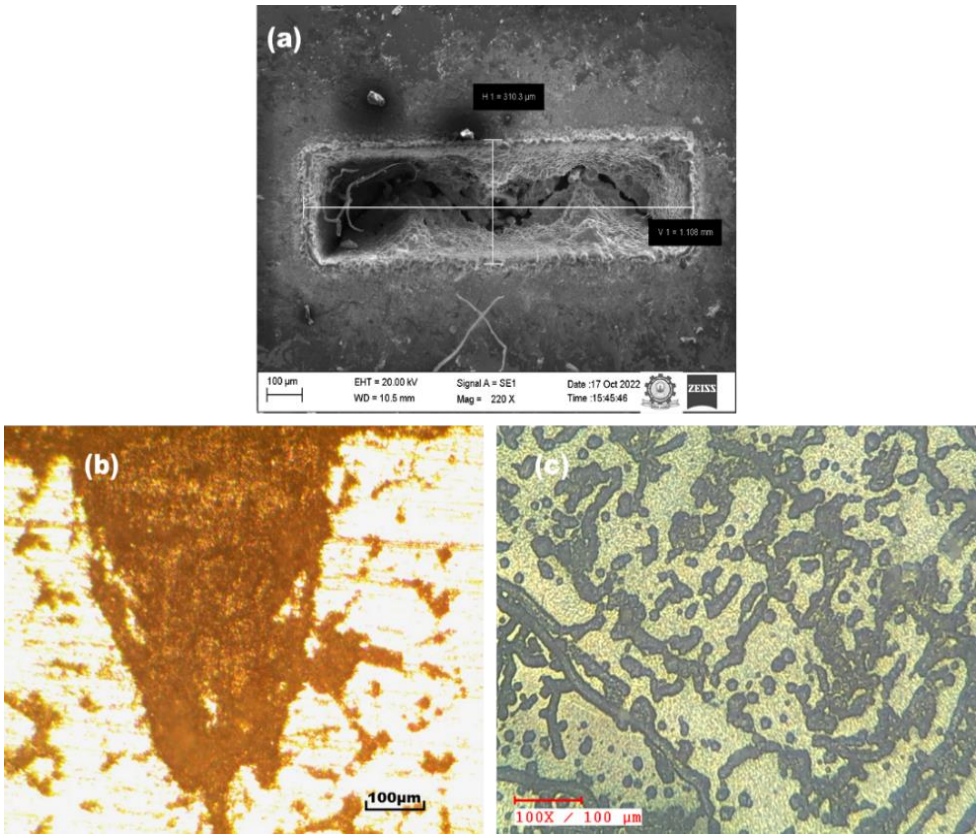

Figure 2 SEM image and optical imaging of the laser engraved micro profile dimension and depth of engrave for 2 watts, 100 mm/sec and 7 kHz

From the result, volume of material removal depends on the laser intensity and it is found maximum for 4 watts – 100 mm/sec process conditions. Impact of laser power and scan speed found to be influencing on volume of material removed rather than the laser frequency. Therefore, based on the profile requirement, the input process parameters are varied to study the response on engraving of modified nickel base superalloy.

8.5 Optimization of machining parameters for micro profile cutting using laser pulse

Evolutionary search algorithm is one of the ancient algorithms used to predict the optimized process for the constraints and / or unconstrained condition. These algorithms are the bio mimics of evolutions in the biological systems. Literatures are available to report on genetic algorithm (GA), particle swarm optimization (PSO), ant colony optimization (ACO) and still the developments on bio – mimics are unrelenting. As an evolution in the bio – mimic algorithms, the chromosomes / populations are handled in different form to increase the efficiency of the algorithm. The genetic algorithm (GA) is a versatile technical process which can be defined for the multi objective optimization with diversified constraints in the problems.

The number of chromosomes in population will be swapped and mutated for the predefined number of generations. The result saturation and process optimization does not meet the expectation in few cases. This might be due to fixed number of populations with distinct probability for swapping and mutation. The development of the population variation in genetic algorithm has reached to expand as Adam – Eve Gene Algorithm. The factors in adam – gene algorithm is slightly modified from conventional genetic algorithm. Some of the highlights are as crossover (reproduction) from single pair randomly generated chromosomes, mutation in chromosomes and death of chromosomes after a defined number of generations. In this algorithm, the chromosomes generated or born during crossover are limited to sustain (to live) for three generations only. The Adam – gene algorithm is similar to Genetic Algorithm with varying population size (GA Vs PS), with a control in population through the death factor. It will control the population by removal of chromosomes after three consecutive generations.

Adam gene algorithm for laser profile cutting process parameters

The objective function for the process parameter optimization is framed to minimize the deviation is micro profile dimensions in terms of width and breadth of the slot. To achieve the dimension, factor the responses are dependent on laser source development such as power, scan speed and frequency. As these parameters do vary the length of the micro profile found with deviation. In order to frame the objective function, an empirical relation in terms of the length and breadth of the profile designed. The regression equation for the profile length (Eq. 5) and breadth (Eq. 6) derived from the statistical tool with the experimental data are as follows:

$$l = 1.0933 + 0.00333P + 0.00026S - 0.00358F \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$$b = 237.2 + 32.6P + 0.846S - 10.56F \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

The deviation in the profile has been dis- cussed in detail with the result findings. The main objective of this research is to find an optimal process parameter for micro profile cutting on nickel – based superalloy. The increase in laser power and scan rate has wide variation in profile geometry. Therefor the objective of the algorithm is to frame a minimum optimization function with respect to laser power (2–4w), scan rate (50–100 mm/sec) and laser frequency of (5–9 kHz). In order to fix the optimal parameter, the weightage for the length (w_1 as 70%) is given more than that of the breadth (w_2 as 30%). It is clear to infer that to reduce the deviation in profile dimension, the objective function has been designed.

$$f(x) = \mathrm{lxw}_1 + \mathrm{bxw}_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

The best solution to be arrived from the population is expected to be minimum. The higher variation is not recommended and the best in population (P_{best}) is as in Eq.8

$$P_{best} = \frac{1}{f(x)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

The laser cutting process used to make the micro profiling on nickel based superalloy using three different process parameter and the results are justified

significantly. To find the optimal process parameter, the experimental data are evaluated to frame the objective function. Using the objective function the process parameters are identified from the search spacedefined in the machine condition. With reference to the machine condition, each process parameters are definedwith a set of binaries (0 and 1) as initial chromosomes.

The maximum generation defined for the algorithm is fifteen and the optimal solution identified is plotted in the graph as shown in Figure 3. The outcome of the adam – gene algorithm has arrived with best in global population at 4th generation. At this generation, the chromosomes derived the optimal parameter as 2.3 w in laser power; scan speed 60 mm/sec and frequency of 5.6 kHz. For this optimal condition the minimum length and breadth of the profile can be arrived aswith 1.1 mm in length and 335µm in breadth for the rectangular profile cutting. Considering the border layers, these parameters may be the best to fit on micro channel cutting.

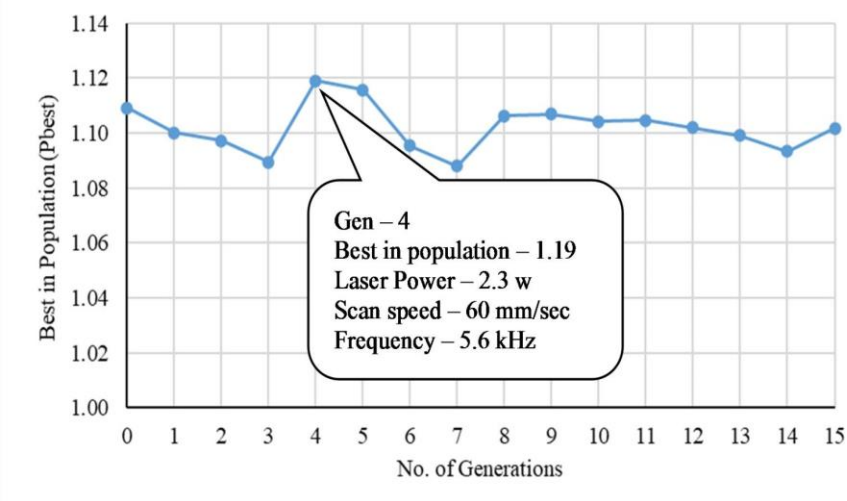

Figure 3 Best in population fromthe adam – gene algorithm forfifteen generations

8.6 Impact of parameters on micro drilled hole diameter

The micro drilling operations of 300µm was performed on Nickel based superalloy using Titanium nitride coated tungsten carbide tool. The impact of process parameters on micro drilled hole diameter can be observed with a field of Scanning Electron microscope and to describe the accuracy and material characteristics. The drill hole diameters are

evaluated with respect to the spindle speed of 1500, 2000, 2500 rpm with feed values as 0.2, 0.4, 0.6 mm/min respectively.

As a result, the minimum feed rate 0.2 and 0.4 mm/min found that accurate drill hole with respect to spindle rotation speed 1500 rpm, minimum depth of cut is 1 has a better diameter of 300.3 µm.as shown in Figure 4. For the same parameters while the increase in depth of cut (2 mm) values, the outcome of drill hole is to deviate the cutting axis and formation of maximum wear rate as shown in Figure 5. At high depth of cut the material has maximum shear zone indicate the material deformation. At increase feed rate to 0.6 mm/min the drill hole gone distorted on the top surface.

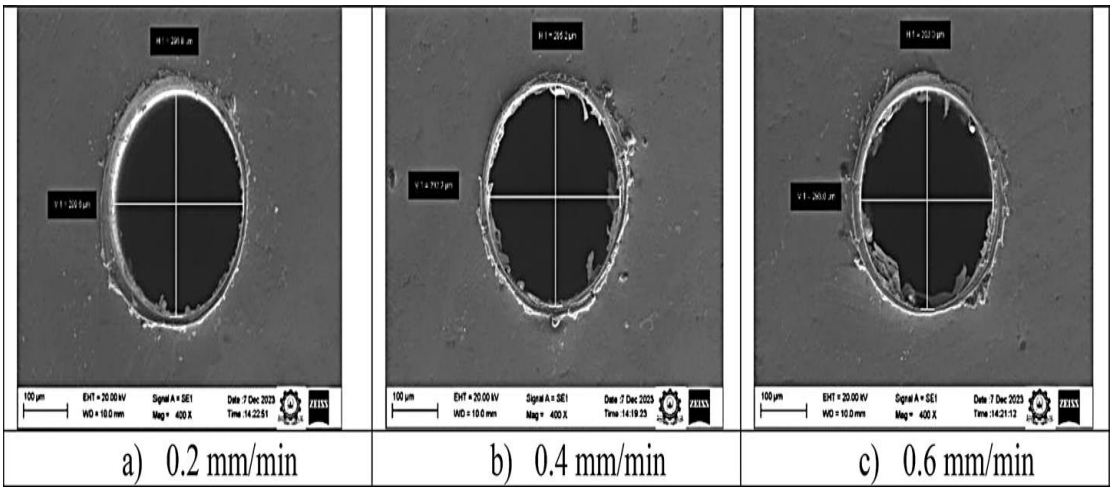

Figure 4 SEM images of micro hole drilled at 1500 rpm with 1 mm depth of cut with different feed rate

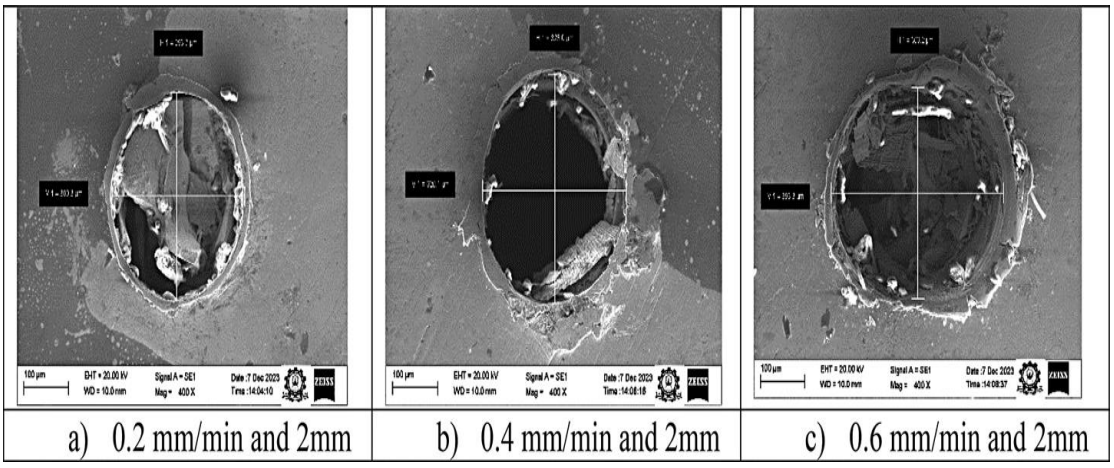

Figure 5 SEM images of micro hole drilled at 1500 rpm with 2 mm depth of cut with different feed rate

8.7 Impact of parameters on Tool wear rate during micro drilling process

Titanium nitride coated tungsten carbide micro drill tool bit after machining the NiCoCr base superalloy using different parameters. The standard diameter of micro drill bit is 300µm. The micro hardness of the work material is 479 HV and the micro hardness of micro drill tool is 640 HV.

The tool wear found in the form of abrasive wear at the tool flute and adhesive wear on the tool tip. The rate of abrasive wear is an average due to the hardness of micro drill tool is 1.5 times harder than the work material. But the adhesive wear is very low. The cutting edge of the micro tool bit is very sharp. As a result, average parameters of feed rate 0.4 and spindle speed 2000 rpm is very better for minimum wear rate as shown in Figure 6. The outcome of tool nomenclature and cutting tool materials are, the tool failure is very less and it's accepted for continuous machining in future. By increasing the parameters of tool rotation speed is 2500 rpm, the micro tool was slightly changed their tip color into a black as shown in Figure 7. In addition, the Micro drill bit was broken due to higher feed rate of 0.6 mm/min.

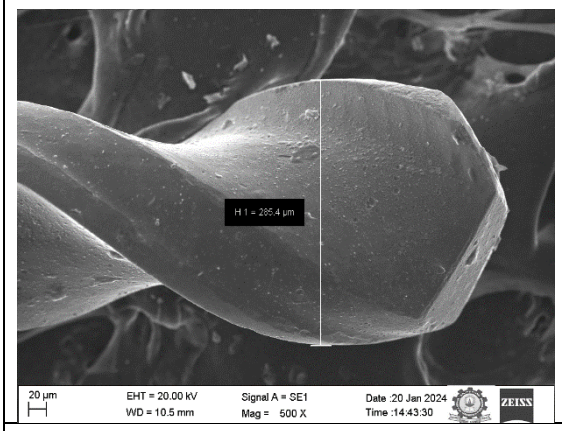

Figure 6 SEM images of micro drill tool bit for feed rate 0.4 mm/min and spindle speed 2000 rpm

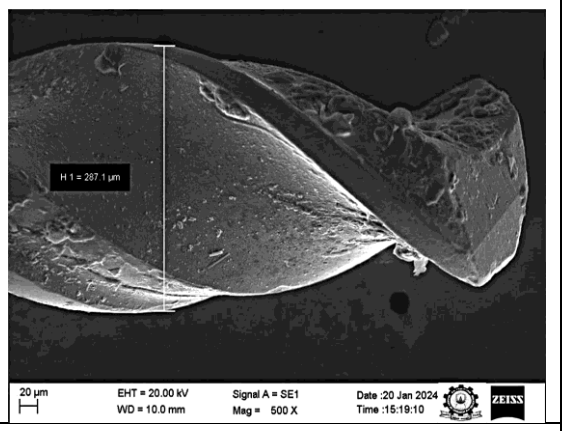

Figure 7 SEM images of micro drill tool bit for feed rate 0.4 mm/min and spindle speed 2500 rpm

8.8 Impact of parameters on machining time and volume of material removed during micro drilling process

The Machining time for micro drilling is calculated with respect to process parameters using a mathematical formula as given in the Table.2. The outcome as shows the impact of parameters on machining time is, an increase the spindle speed rotation was observed to lower machining time. At minimum spindle speed of 1500 rpm machining resulting is increasing the machining time and slowly removal of material. From this study, the minimum machining time is influenced by maximum spindle speed of 2000 rpm and minimum feed rate of 0.2 mm/min. The minimum machining times are an important key factor to make mass production.

Table 2 Control parameters and output responses from micro drilling

Ex No	Voltage (V)	Feed rate (mm/min)	Tool speed (rpm)	Length of the cut (mm)	Machining time (min)	Material removed (mm^3)
	Control parameters				Output responses	
1.	10	0.2	1500	1	3.33	0.06730
2.	10	0.4	1500	1	1.66	0.0781
3.	10	0.6	1500	1	1.11	0.0718
4.	10	0.2	2000	1	0.1	0.0691
5.	10	0.4	2000	1	0.2	0.0682
6.	10	0.6	2000	1	0.83	0.0707
7.	10	0.2	2500	1	2	0.0667
8.	10	0.4	2500	1	1	0.0213
9.	10	0.6	2500	1	0.66	0.0701

9. RESEARCH FINDINGS

The following research findings were based on the experimentation results and the characterization of the machined specimens.

9.1 Summary of experimental and characterization studies of wire electro spark erosion technique

The SR, MRR and metallurgical characterization of NiCoCr base superalloy machined using wire electro spark erosion technique and the following conclusions were made.

1. The pulse on duration has highly influenced (53%) towards the surface roughness followed by the applied voltage (30%). Subsequently, for material removal rate the applied voltage is the predominant factor (87%) and the pulse on duration (2%) respectively.

2. The developed empirical relation between the process parameters (i.e., SON, SOFF & V) and machining attributes (i.e., Surface roughness and Material removal rate) is accurate and the model is significant at 94.1% confidence limit.

3. The Voltage is directly proportional to the material removal rate and other two parameters SON, SOFF time have less contribution towards thematerial removal rate.

4. The optimum setting for smaller surface roughness and larger material removal rate is found out using ANOVA.

5. The SEM characterization reveals that there is a micro crack and the micro voids over the surface of the material. The recast layer intensity increases with the increase in the SON time this may be due to the deposition of melted metal over the material surface.

9.2 Summary of experimental and characterization studies of micro drilling using laser beam machining

The functional material NiCoCr base superalloy micro drilled using laser beam technique and the following summary were made.

1. The micro profile machined with a short pulse has better accuracy. The depth of the micro profile has wide range of variation from 476 to 650 μm.

2. However, the rotating locus for the short pulse has removed the minimum material, and the dimension is closer to the design.

3. The influence of pulse in laser cutting has been studied in terms of surface quality. A long pulse laser has induced the material with maximum heat energy. The width of the heat-affected zone was wider to a depth of 150μm.

4. In short-pulse laser, the material removal is in the form of ablation. The heat energy generated during machining is completely eradicated, and the material is removed because of the force generated by the short pulse.

5. It has been confirmed that the short-pulse laser machine has physical ablation in the form of shear to machine the material. Therefore, short-pulse laser machining is recommended for the micromachining of hard material.

9.3 Summary of experimental and characterization studies of micro drilling using conventional mechanical drilling

The experimental investigations on micro drilling of NiCoCr base superalloy with Tungsten coated carbide tool drillbit, the summary of results are as follows.

1. The average speed machining at a spindle speed of 1500 RPM is a justifiable parameter to produce an average diameter of 300.3 μm drill hole close to design diameter (300 μm) and it has been achieved with a minimum feed rateof 0.2 mm/min.

2. For the same parameters while the increase in depth of cut (2 mm) values, the outcome of drill hole is to deviate the cutting axis and formation of maximum wear rate.
3. The dynamic fluctuation increases have induced the drill tool in the form of tool buckling and outing.

4. At increasing the parameters, the drill open diameter faces maximum shear and material deformation likechip formation and burring.

5. The thrust force and fluctuation in cutting drill bit, the tool wear found drastic in the cutting-edge material shear during the cutting process adheres on the path of drill flute.

10. ORGANIZATION OF THESIS

Chapter 1: This chapter illustrate about the basics of functional material and their manufacturing strategy. The NiCoCr system of material and the application if the materialin the field of aerospace, automobile, etc. Further the chapter presents the machining methodologies of the NiCoCr system of materials.

Chapter 2: This chapter describes a detailed literature study on the recent research on the NiCoCr materials in the field of machining a Wire electro spark erosion, Pulsed laser beam and Conventional micro drilling process.

Chapter 3: This chapter explain the research gap initiated from the detailed literature survey.

Chapter 4: This chapter explain the objectives the proposed research methodologies were developed.

Chapter 5: This chapter explains the methodology of experimentation and its equipment's. The measurement and characterization methods and procedure for investigation also discussed in detail.

Chapter 6: In this chapter, explains the study of machining of the NiCoCr system by using the WESE process. The mechanism of the machining and the outcomewas also discussed with the help of Table.

Chapter 7: In this chapter, briefly explains the study of machining of the NiCoCr system by using the Laser beam machining. The mechanism of the machining and the outcome was also discussed.

Chapter 8: In this chapter, briefly explains the study of machining of the NiCoCr system by using the Mechanical based micro drilling. The mechanism of the machining and the outcome was also discussed with the help of table and SEM images.

Chapter 9: Based on the results and discussion, the conclusions are made for the research work and the future scopes of the work were discussed in this chapter.

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LIST OF PUBLICATIONS

1. **S.R.Stalin**, Adam Khan, J T, Winowlin & N C, Brintha. Experimental assessment and Adam gene algorithm to optimize the process parameter for micro profile cutting on CM247 alloy using pulsed laser machining process, *International Journal on Interactive Design and Manufacturing (IJIDeM),* **18** (2023) 1-10.

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3. **S.R.Stalin**, M.Adam Khan, J.T.Winowlin Jappes. Studies on machining performance and surface quality of nickel based super alloy using micro drilling process, *Interactions,* **245** (106) (2024).